

# EFFECT OF RANGE ON APPARENT HEIGHT AND FREQUENCY OF HIGH-ALTITUDE RADAR PRECIPITATION ECHOES

A. J. KANTOR and D. D. GRANTHAM

Air Force Cambridge Research Laboratories, Bedford, Mass.

## ABSTRACT

Overestimation of the height of radar precipitation echoes increases with horizontal distance from the WSR-57 radar as a result of the combined effect of earth curvature, atmospheric refraction, and beam width. Radar operating procedures include altitude corrections for these effects. It has been suspected that even after application of these corrections, a bias exists toward higher echoes and greater-than-expected frequencies with increasing distance from the radar. In this paper, empirical estimates of the magnitude of the errors in echo altitude have been determined by regression techniques for 13 WSR-57 radar stations. For echoes  $\geq 50,000$  ft, the average echo altitude increase is less than 1,000 ft for distances up to 100 mi. It was also found that echo frequencies increase proportionally with the area of each additional 10-mi annulus. Consequently, errors in echo altitude and frequency of occurrence due to range effects should be considered insignificant for distances out to 100 mi for the WSR-57 radar.

## 1. INTRODUCTION

Horizontal distance from a radar installation has long been considered a significant factor in the change in apparent height and frequency of occurrence of high-altitude precipitation echoes, particularly those above 50,000 or 60,000 ft. This suspected bias toward both greater altitude and greater-than-expected frequency with increasing range has been reported by a number of authors in recent years. For example, Sanford (1961) indicated an increase in height of 7,000 to 8,000 ft for severe storms at 180 mi from a CPS-9 radar located at Texas A&M. Similarly, Jordan (1962) showed that a disproportionately large number of echoes above 60,000 ft was detected at distances greater than 150 mi at nine CPS-9 stations and at 75 to 100 mi from 10 WSR-57 locations. With respect to beam width (CPS-9:  $1^\circ$ , WSR-57:  $2^\circ$ ), 150 to 200 mi from a CPS-9 radar is comparable to 75 to 100 mi from a WSR-57 radar. Also, the range-height indicator on the WSR-57 is limited to a 100-mi range.

In this study, echo frequency and height biases due to range effects have been investigated to provide improved interpretation of observations of these high-altitude radar echoes. These apparent biases have been empirically determined and evaluated for echoes detected out to 100 mi by the WSR-57 radar.

## 2. DATA

Under AFCRL sponsorship, the Environmental Science Services Administration (ESSA) has compiled hourly frequencies of echo tops  $\geq 50,000$  ft for 13 climatically representative WSR-57 radar stations in the United States. Data for these stations, denoted by the circled dots in figure 1, were compiled for 6 yr, 1962 through 1967. Frequencies of echoes were taken from hourly observations

at the WSR-57 stations, and the maximum height to which echoes protruded for each hourly observation was recorded. Values were tabulated every 1,000 ft in altitude by 10-mi range intervals from 10 to 100 mi from each radar. For each station, echoes  $\geq 50,000$  ft were related linearly to range by "a line of best fit,"  $Y=a+bX$ , with the regression constant,  $a$ , and coefficient,  $b$  (slope), determined by least squares. The number of echoes at each location varied from 138 at Evansville, Ind., to 2,197 at New Orleans, La. For comparison, two additional regression lines were computed from data for all 13 stations; one line was for all echoes  $\geq 50,000$  ft, and the other for all echoes  $\geq 60,000$  ft. For echoes  $\geq 50,000$  ft, 10,605 observations were available, and for echoes  $\geq 60,000$  ft, 626 observations were available.

## 3. LIMITATIONS

The ESSA WSR-57 radar network was chosen as the data source for this study for three reasons: all 31 stations shown in figure 1 are continuously operated; the radar meteorologists and observers are all technically and uniformly trained; and the radars are well maintained, with range-height indicators calibrated quarterly.

The relatively large  $2^\circ$  beam width is one of the most limiting characteristics of the WSR-57 since the beam diameter increases to approximately 20,000 ft at a 100-mi range. Additional limitations in the data, and accuracy and limitations of the WSR-57, were discussed recently by Grantham and Kantor (1967) in a report on radar echo distributions. In that report, for example, 21 radar echoes at altitudes between 40,000 and 65,000 ft in the south-central United States were paired with and verified by 21 U-2 aircraft observations of clouds. The comparisons are shown in figure 2. Contrary to theoretical estimates that WSR-57 radars would pro-

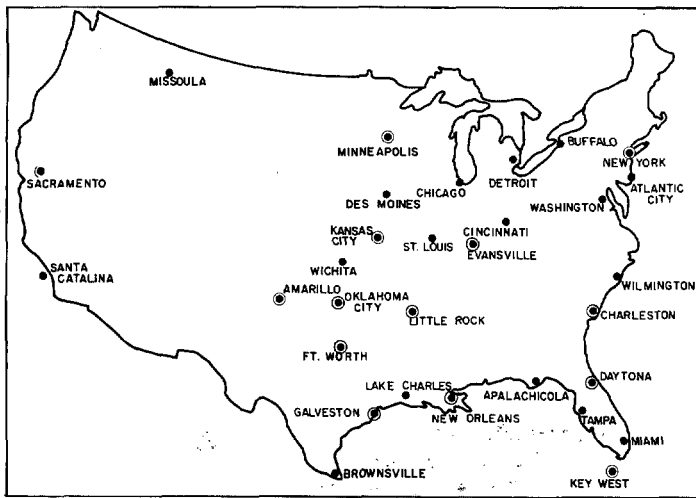


FIGURE 1.—WSR-57 weather radar network.

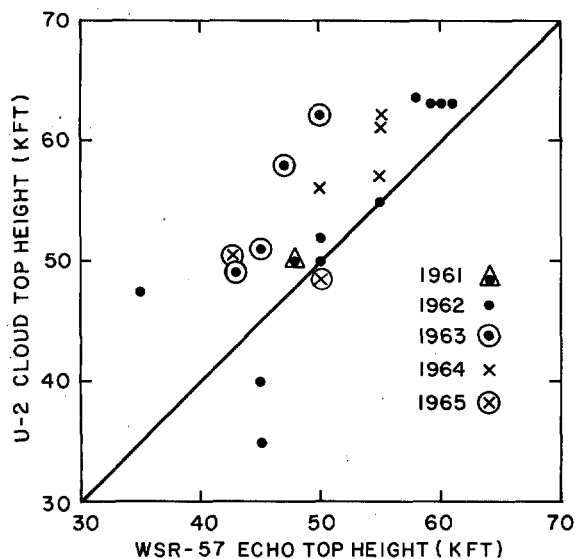


FIGURE 2.—Comparison of WSR-57 echo tops with U-2 cloud tops.

vide tops that were biased toward unrealistically high altitudes, figure 2 shows that U-2 measured and estimated cloud tops were 4,000 ft higher, on the average, than the radar measurements. The root-mean-square height difference is 6,500 ft. According to Saunders and Ronne (1962), a 4,000-ft-average difference is approximately that which might be expected between the top of precipitation-size droplets that can return a radar impulse and the top of visible clouds. Consequently, for these 21 comparisons, the WSR-57 radar provided reasonably accurate altitude estimates of high-level convective clouds.

#### 4. DISCUSSION

WSR-57 procedures and operational capabilities are discussed in detail in the two latest weather radar manuals (U.S. Weather Bureau, 1964, and U.S. Weather Bureau

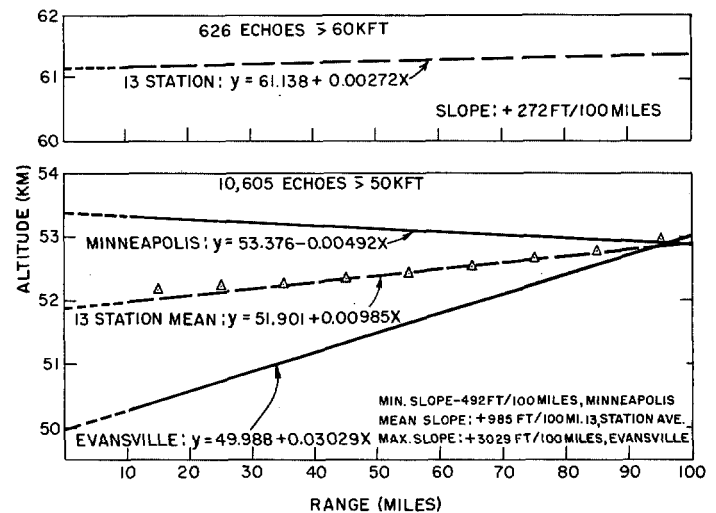


FIGURE 3.—Apparent height change with range of high-altitude radar echoes; minimum (MIN.), maximum (MAX.).

et al., 1967). Included in these reports are analyses of the radar characteristics, such as beam width, and additional problems such as "spike" echoes and other side-lobe effects.

According to these 1964 and 1967 weather radar manuals, all WSR-57 echo top measurements are referenced to mean sea level and have been corrected downward to account for the combination of three known major range effects—earth curvature, atmospheric refraction, and beam width. Also, to better compare echoes at various horizontal distances, range normalization (effective to 125 mi) is utilized with the WSR-57; that is, echoes of equal reflectivity at different ranges appear with the same intensity on radar scopes. As previously indicated, despite application of these corrections, Sanford (1961), Jordan (1962), and others have suggested that echo altitude increases and frequencies are greater than expected with increasing horizontal distance from the radar.

In this study, the magnitude of the unexplained range effect on the apparent altitude of echoes  $\geq 50,000$  ft has been empirically determined and evaluated for the 13 stations circled in figure 1. Figure 3 depicts a least-squares regression line for each of the two extremes of height change, Evansville, Ind., and Minneapolis, Minn., as well as for the 13-station average. Although the height change in 100 mi varies from an increase of 3,029 ft at Evansville to a decrease of 492 ft at Minneapolis, changes were positive or near zero for all stations except Minneapolis. The 13-station mean line indicates an increase of less than 1,000 ft. For comparison, the triangles shown around the mean regression line represent a quadratic paraboloid fit to the data. The agreement between the line and curve is obvious. That is, both the curvature and very small reduction in variance of the quadratic fit over that of linear fit suggest that no radical changes in echo height occur in the outer portion of the 100-mi range. Regression lines were also computed for Kansas City, Mo., for each year 1962

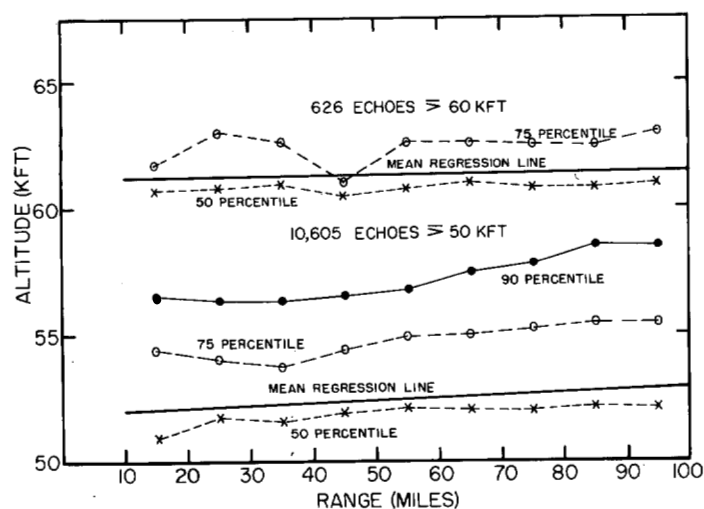


FIGURE 4.—Comparison of percentiles of echo heights with mean regression lines.

through 1967 and for each month, May through September. Although the sample sizes for these regression lines were too small for definitive conclusions, ranging from 91 to 336, there did not appear to be any systematic annual or seasonal effects on the range-height relationship.

For further comparison and verification of the 100-mi height change, a 13-station regression line for echoes  $\geq 60,000$  ft also was computed and is shown in the upper portion of figure 3. Its height increase is only 272 ft in 100 mi.

In figure 4, percentiles of echo tops  $\geq 50,000$  and  $60,000$  ft are compared with the corresponding 13-station mean regression lines. Since the number of observations in the  $60,000$ -ft category is relatively small, only 1/17 as large as for  $50,000$  ft, the 90 percentile has been omitted, and even the 75 percentile shows evidence of instability. Both 50 percentiles, however, agree well with the altitudes and slopes determined by the regression technique.

In figure 5, relative frequency of echoes  $\geq 50,000$  and  $60,000$  ft, based on more than 10,000 and 600 observations, respectively, is related to surface area by 10-mi annuli from 10 to 100 mi from the radar. According to a chi-square goodness-of-fit test, the difference between frequency of occurrence of these echoes and relative surface area is not significant. Consequently, although echo frequencies increase with distance, they apparently are roughly proportional to area at each 10-mi annulus out to a 100-mi horizontal range.

## 5. CONCLUSIONS

The combined effect of earth curvature, atmospheric refraction, and beam width causes overestimation of the altitude of WSR-57 radar echoes as range increases to at least 100 mi. Though corrections for these range effects are applied, a number of authors have suggested that precipitation echo heights and frequencies increase disproportionately with horizontal distance from the radar.

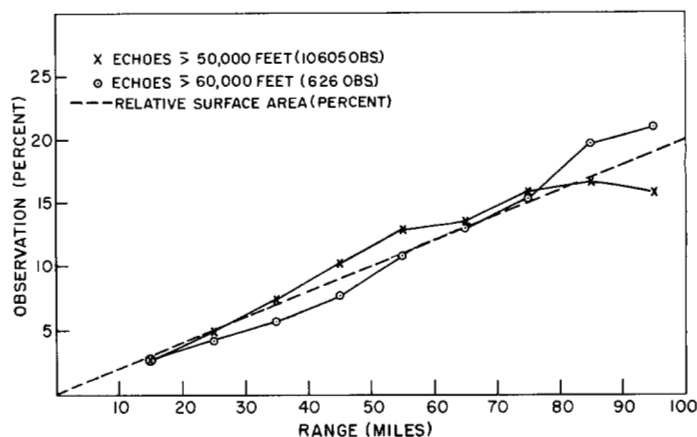


FIGURE 5.—Percent of radar echoes related to surface area by 10-mi annuli; observations (OBS).

This study has shown:

- 1) Mean echo height increases by less than 1,000 ft in 100 mi for echoes  $\geq 50,000$  ft, and less than 300 ft for echoes  $\geq 60,000$  ft.
- 2) Although high-altitude echo frequencies have been found to increase with range, the change is approximately proportional to the change in area for each 10-mi annulus out to 100 mi.

In summary, errors in echo altitude and frequency of occurrence due to range effects can be considered insignificant for distances up to 100 mi for the WSR-57 radar. These results may also apply to other weather radars, such as the CPS-9, provided appropriate corrections are applied and operational standards are on a par with WSR-57 procedures.

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